Initial Results from DS1: IPS Diagnostics Sensors (IDS)

David E. Brinza, *et al*
Jet Propulsion Laboratory
California Institute of Technology
david.e.brinza@jpl.nasa.gov
(818)354-6836

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Goal for IDS

- **Understand the local environment on a spacecraft utilizing an Ion Propulsion Subsystem (IPS)**
  - **What is the nature of the local plasma environment?**
  - **What is the IPS contamination environment?**
  - **Are there EMI/EMC concerns?**
  - **Are IPS DC-magnetic fields compatible with science measurement requirements?**

IDS Approach

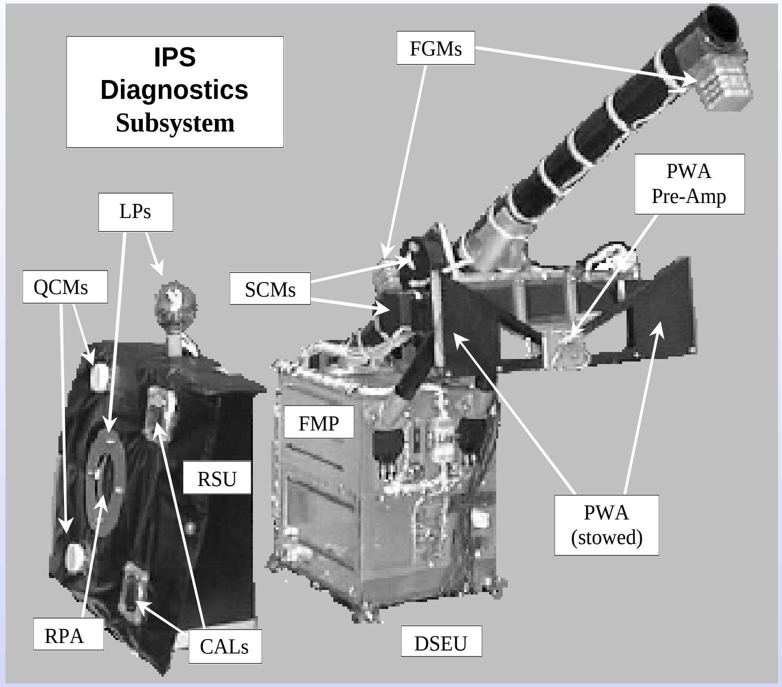
- **Conduct a balanced investigative effort that includes the following**
  - **Flight measurements with integrated sensor package**
  - **Ground laboratory measurements for correlation**
  - **Models based on physical principles and mechanisms**
- **Provide the user community with results and models for designing future IPS science missions**

IDS Team Members

- **JPL**
  - **FMP: M. Henry, A. Mactutis, K. McCarty, J. Rademacher, T. vanZandt, K. Leschly, B. T. Tsurutani**
  - **Modeling: J. J. Wang**
- **Technical University of Braunschweig**
  - **FGM: G. Musmann, I. Richter, C. Othmer, K-H. Glassmeier**
- **TRW**
  - **PWS: S. Moses, R. Johnson**
- **Maxwell Technologies**
  - **Modeling: I. Katz, V. Davis, B. Gardner**
- **Physical Sciences, Inc.**
  - **DSEU (SAMMES heritage: BMDO) and Calorimeters: E. Lund, P. Joshi, M. Hinds, B. D. Green**

IDS Flight Hardware

- **IDS is a compact, highly-integrated sensor suite**
  - **Mass: 8 kg**
  - **Power: 21W , 7W (standby)**
  - **Spacecraft Interfaces:**
    - 28 VDC (±6 VDC), MIL-STD-1553B
- **IDS samples continuously**
  - **RSU sensors at 2 second intervals**
  - **FMP scans at 16 second intervals**
  - **Waveform transient recording**
    - PWA, SC at 20 kHz, 1 second
    - FGMs at 20 Hz, 55 seconds



<u>**Remote Sensors Unit (RSU):**</u>
Plasma: 2 Langmuir Probes(LPs), Retarding Potential Analyzer (RPA)
Contamination: 2 Quartz Crystal Microbalances (QCMs), 2 Calorimeters (CALs)
<u>**Diagnostic Sensors Electronics Unit/Fields Measurement Processor (DSEU/FMP):**</u>
Electrostatic Fields: 2-m dipole Plasma Wave Antenna (PWA) with pre-amplifier
Electromagnetic Waves: 2 Search Coil Magnetometers (SCMs); 1 failed before launch
DC Magnetic Fields: 2 ea. 3-axis Flux-Gate Magnetometers (FGMs)

IDS Sensor Performance

- **IDS sensors were calibrated over the operating temperature range (-25°C to +55°C)**
- **Measurement capabilities summarized below**

Sensor	Measurement	Range	Resolution
QCMs	Mass/area	0 to 500 $\mu g/cm^2$	0.01 $\mu g/cm^2$
CALs	Solar Absorptance (α) Hemi. Emittance (ε)	α = 0.08 (BOL) to 0.99 ε = 0.05 to 0.85 (BOL)	$\Delta\alpha$ = 0.01 $\Delta\varepsilon$ = 0.01
LPs	Probe Current Probe Voltage	I =-0.4 to 40 mA V = -11 to +11 VDC	1% 0.1V
RPA	Current (Gain Select) Grid Bias Voltage	I = 0.01, 1, 10, 100 μA V = 0 to +100 VDC	1% 0.4V
PWA	E-field (Adjust. Gain) 24 Freq. Channels *	50 to 160 dBμV/m 10 Hz to 30 MHz (4/decade)*	$\pm$ 3 dBμV/m $\pm$ 40% (-3dB)**
SCM	B-field (Adjust. Gain) 16 Freq. Channels *	80 to 160 dBpT 10 Hz to 100 kHz (4/decade)*	$\pm$ 3 dBpT $\pm$ 40% (-3dB)**
FGMs	Magnetic Field Vector **	$\pm$25,000 nT	0.5 nT

*** Typical band separation** **** Typical Bandwidth**

IDS Configuration on DS1

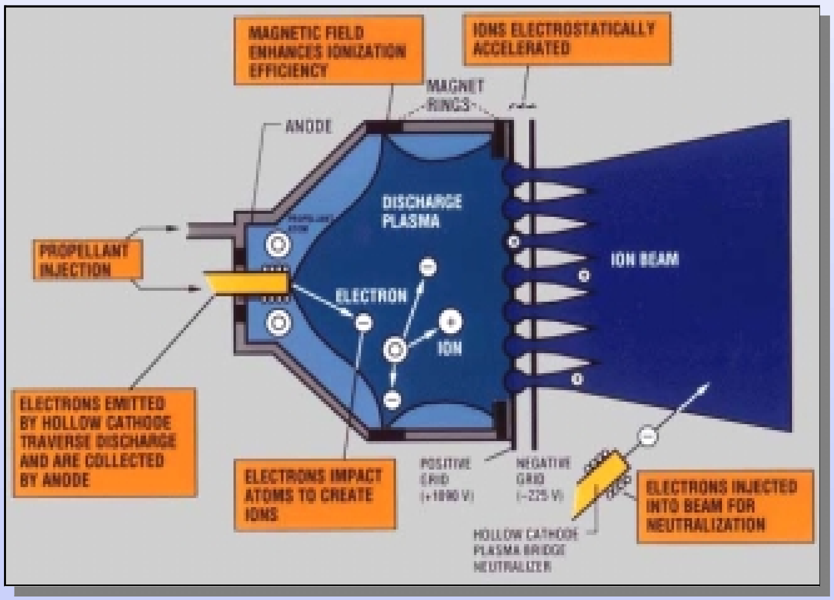
- DSEU in shade
- PWA/boom assembly exposed to the Sun
- RSU sensors 45° from nom. sun vector
- Direct line-of-sight to IPS grid for lower pair of contamination monitors (CMs)
- Upper CM pair is shadowed from IPS

IPS Operation and Charge Exchange Xenon Ions

- **IPS produces beam and cold, dense plasma flow**
  - IPS ionizes 80% to 90% of xenon in discharge chamber
  - Fast beam ion strips electron from slow thermal xenon atom

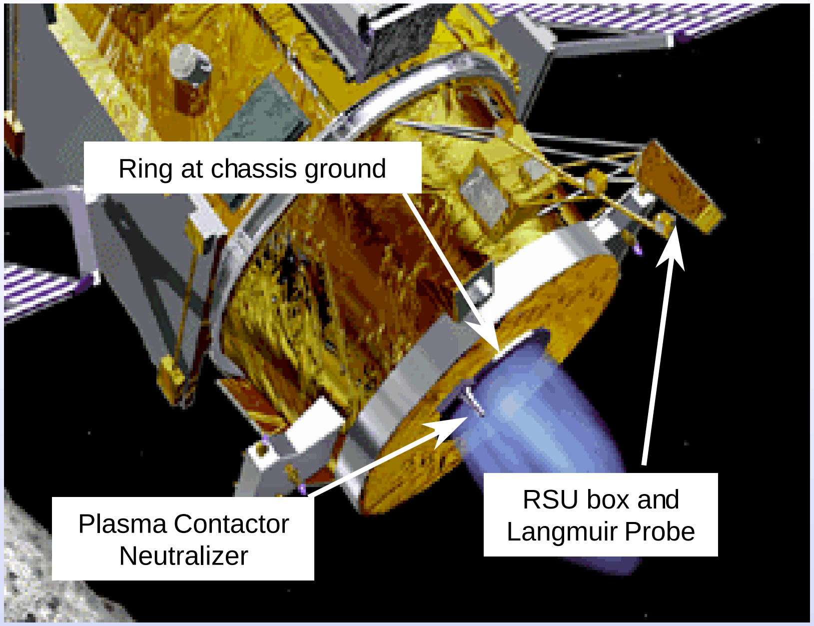
    $$Xe^{+}_{beam} + Xe^{0}_{thermal} \longrightarrow Xe^{0}_{beam} + Xe^{+}_{CEX}$$

  - "Charge-exchange xenon" (CEX) ions driven by local E-fields



- **CEX ions affect these environmental factors**
  - DS1 chassis potential
  - IPS contamination
  - Plasma wave noise

IPS Current Balance on DS1



- **Current balance determines the net charge on DS1**
- **Net charge determines the DS1 chassis potential with respect to solar wind “ground”**

- **Key contributors to current balance on DS1 are:**
  - **IPS ion beam**
  - **IPS neutralizer**
  - **DS1 spacecraft chassis (IPS thruster mask ring)**
  - **IDS Langmuir Probes with conductive black Kapton MLI on RSU**

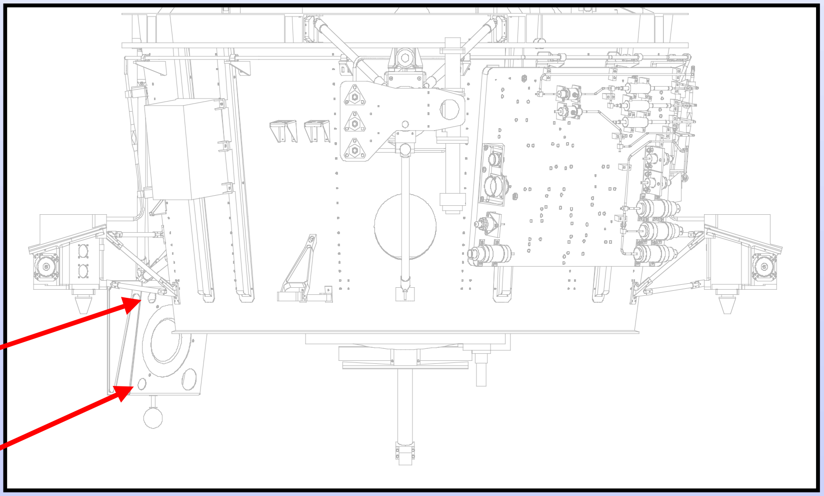
IPS Plasma Effects

- **IPS CEX plasma current collection drives the DS1 chassis from -6 to -10 V relative to space "ground"**
  - **Current collection affected by plasma density (10^{12} m^{-3}) and electron temperature (1.2 to 2.0 eV)**
  - **CEX ions from IPS plume "orbit" DS1**
- **Significant CEX ion flux detected by PEPE during IPS operations**
- **Solar wind proton measurements by PEPE essentially unaffected by IPS operations**
  - **Effects on solar wind electrons not quantified**

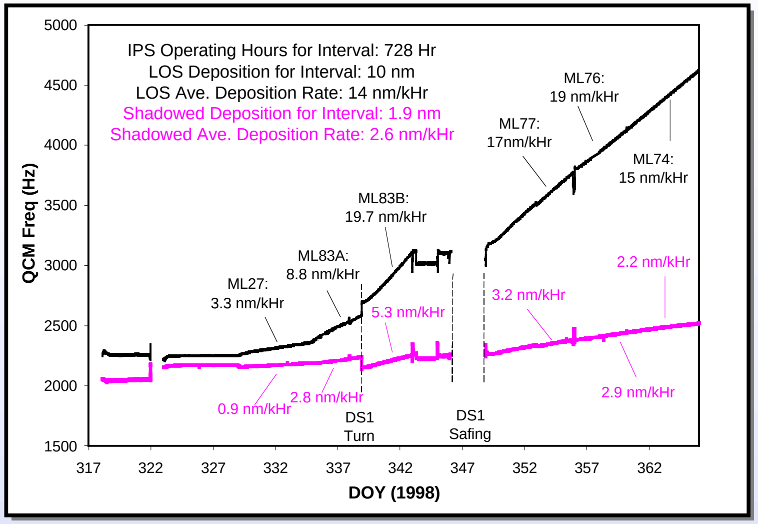
Contamination from IPS

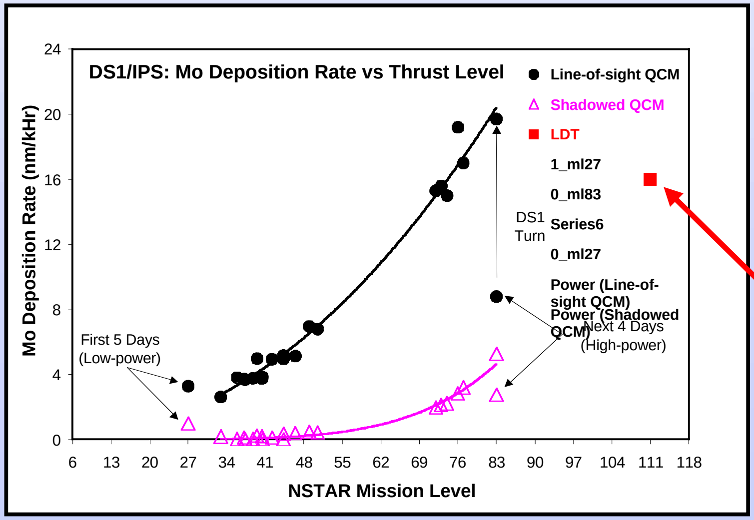
- **IPS wear-out mechanism is grid erosion**
  - CEX ions accelerated into outer grid (-150 to -250V)
  - Grid material (molybdenum) is sputtered by CEX ions
  - Sputtered material can collect on nearby surfaces
  - Ionization of Mo atoms in plume leads to non-line-of-sight transport and deposition

- **RSU configuration on DS1 yields two distinct contamination monitor environments:**
  - Shadowed region, shielded by spacecraft structure
  - Direct line-of-sight (LOS) to IPS thruster grid



IDS Contamination Measurements





- **Mo deposition readily detected by QCMs**
  - **Line-of-sight deposition shown in figure to left is >5x shadowed sensor**
  - **Sun-orientation effect on deposition for ML83A/B (DOY 98-335 to 98-344)**
- **Mo deposition rate vs IPS Mission Level (ML)**
  - **Correlates with current collected by outer grid**
  - **Highest IPS levels only at beginning of mission**
  - **Ground test (LDT) result is for maximum IPS ML**

IPS Contamination Effects

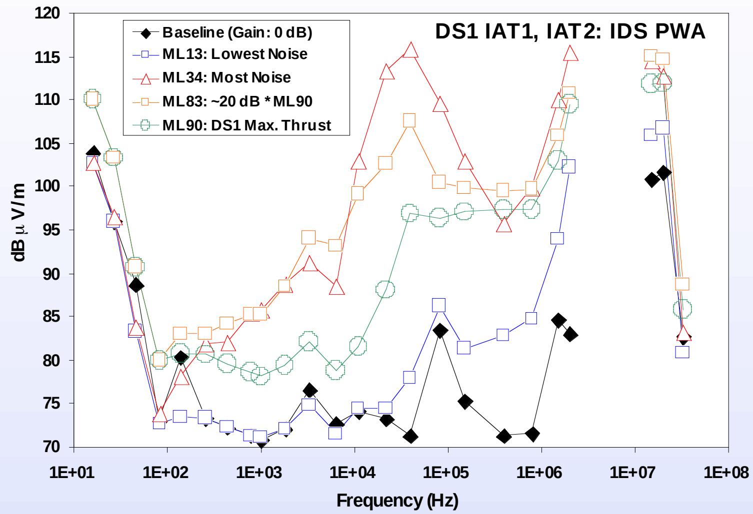
- **Line-of-sight deposition rate correlates with long-term ground test experience**
  - 25 nm Mo accumulation after 3500 hours IPS operation
  - Expect highest grid erosion early in operating life
  - Extrapolating DS1 rate to ground results is difficult
  - Surface thermo-optical properties changed rapidly for line-of-sight: $\Delta(\alpha/\varepsilon)$ ~ 0.3 in several days at ML83
- **Non-line-of-sight deposition effects minor**
  - 2.5 nm Mo accumulation after one year
  - Chamber effects invalidate ground correlation
  - Effect on SCARLET arrays is immeasurably small due to geometric effect (ions are likely to be repelled by positive array voltage)

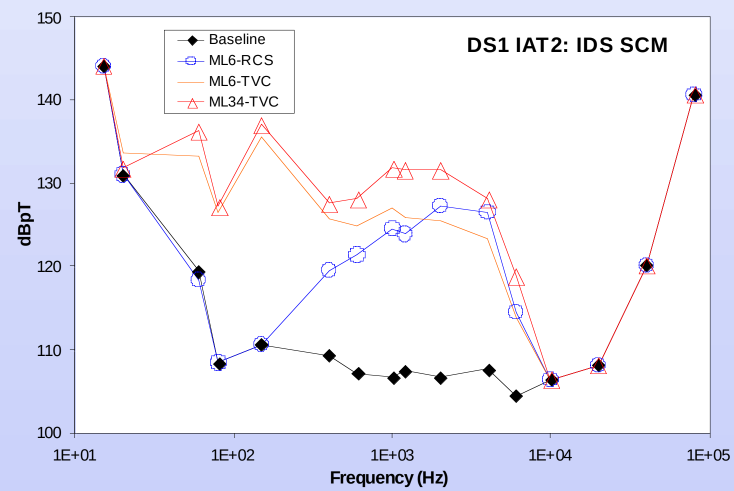
IPS EMI/EMC

- **Hollow-cathode discharge plasma sources produce substantial electrostatic noise**
  - Electron density fluctuates with discharge instabilities
  - CEX plasma serves as conductive medium for noise
- **IPS produces momentary arcs during ignition and “recycle” events**
  - Ionization arcs between grids causes IPS to cycle beam power supplies
- **Plasma plume and beam extend over large distances (~km) from IPS**
  - Potential for interference with RF telecommunications link

IDS Plasma Wave Measurements

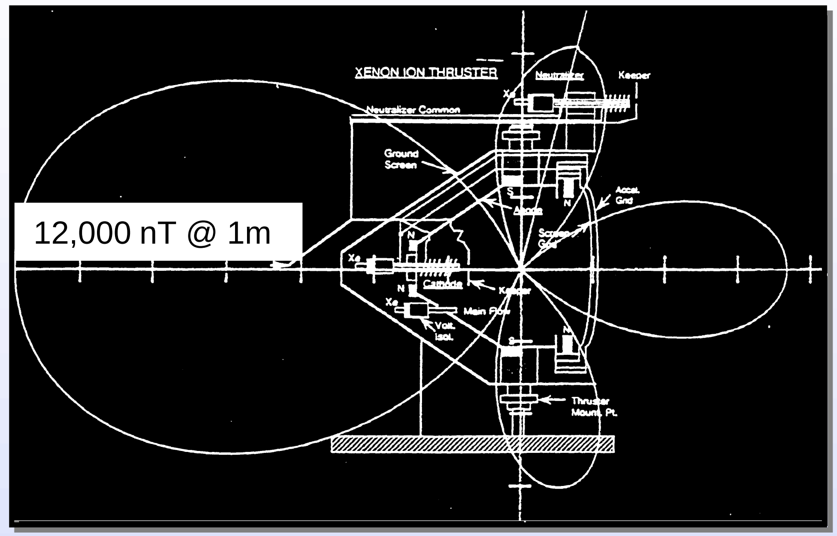
- **Plasma Waves**
  - **<120 dBμV maximum**
  - **IPS ignition or recycles produce peak amplitude signals comparable to hydrazine thruster firings (<140 dBμV/m)**
- **EMI (AC B-field)**
  - **IPS produces EM noise (<140 dBpT @ 2 kHz)**
  - **Ion engine gimbal motors for TVC produce similar EMI levels at 100 Hz**
  - **IPS has <u>no impact</u> on telecommunications link**





IPS DC Magnetic Field

- **Sm_2Co_{17} magnet rings within IPS thruster**
  - **"Ring-cusp" geometry to improve IPS xenon ionization efficiency**
  - **External fields ~10,000 nT at 1 meter distance**
  - **Temperature-dependence characterized in flight**



- **Magnetic field stability and science measurements**
  - **Temperature-corrected DC fields stable within 5 nT after 1 year operation (< 0.1% change since launch)**
  - **No long-term degradation trend for magnetic fields obvious**
  - **Short-term magnetic field stability allows measurement of fluctuations (> 1 nT) of external B-fields**

IDS Conclusions

- **IPS local environment well-characterized**
  - **CEX plasma affects DS1 chassis potential**
    - CEX ions surround DS1, substantial ion flux for particle spectrometers, solar wind protons unaffected
  - **Local line-of-sight contamination rates are substantial**
    - Non-line-of-sight contamination rates are significantly lower
  - **Plasma waves are produced by IPS**
    - Peak amplitudes are equivalent to other sources on DS1 (hydrazine thruster firings, IPS gimbal motor operations)
- **Further investigations in progress**
  - **Effects of sun-orientation on chassis potential**
  - **Long-term contamination rates vs IPS ML**
  - **Plasma wave noise dependence on IPS operating conditions (Why is ML90 much quieter than ML83?)**